PROCEEDINGS

OF

THE ROYAL SOCIETY.

May 1, 1890.

Sir G. GABRIEL STOKES, Bart., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

In pursuance of the Statutes the names of the Candidates recommended for election into the Society were read from the Chair as follows:—

Baker, Sir Benjamin, M.Inst.C.E.
Bosanquet, Robert Holford Macdowall, M.A.
Burbury, Samuel Hawkesley, M.A.
Gardiner, Walter, M.A.
Kerr, John, LL.D.
Lea, Arthur Sheridan, D.Sc.
MacMahon, Percy Alexander, Major R.A.
Norman, Rev. Alfred Merle, M.A.
Perkin, Professor William Henry, jun., F.C.S.
Pickering, Professor Spencer Umfreville, M.A.
Roberts, Isaac, F.R.A.S.
Sharp, David, M.B.
Teall, J. J. Harris, M.A.
Thorne, Richard Thorne, M.D.
Weldon, Walter Frank Raphael, M.A.

The following Papers were read:—

I. "Magnetic Properties of Alloys of Nickel and Iron." By J. HOPKINSON, D.Sc., F.R.S. Received April 17, 1890.

Eight different alloys have been examined, distinguished here by the letters of the alphabet. All the samples were given to me by Mr. Riley, of the Steel Company of Scotland, who also furnished me with the analysis given with the account of the experiments with each sample.

The methods of experiment were the same as were detailed in my paper on "Magnetic and other Physical Properties of Iron at a High Temperature." The dimensions of the samples were also the same. For this reason it is unnecessary to recapitulate the methods adopted. I confine myself to a statement of the several results, dealing with each sample in succession.

A. The following is the analysis of this sample :—

Fe.	Ni.	C.	Mn.	S.	P.	
97·96	0·97	0·42	0·58	0·03	0·04	per cent.

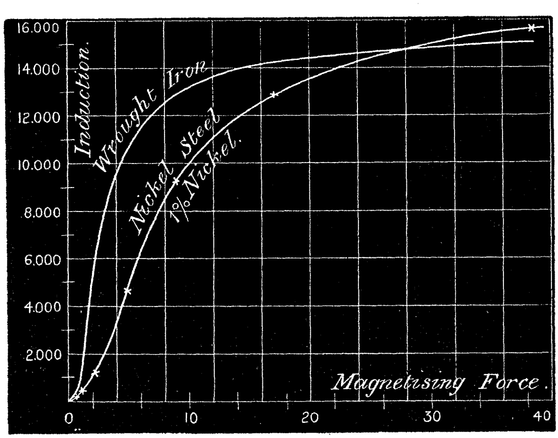
In this case a magnetisation curve is all that I have obtained free from doubt; the sample was heated and its magnetisation determined at various temperatures for a force of 0·50, but the higher temperatures must be taken as a shade doubtful, as the secondary broke down before cooling, and I cannot be sure whether or not the secondary may have changed.

Table I gives the results at the ordinary temperature for the material before heating; these are plotted in Curve 1 together with the curve for wrought iron, for comparison.

Table I.

Magnetising force.		Induction.
0·06	......	11
0·12	......	29
0·26	......	58
0·53	......	122
1·07	......	303
2·14	......	995
4·7	......	4,560
8·8	......	9,151
16·8	......	12,876
38·9	......	15,651
270·0	......	21,645

Curve 1.

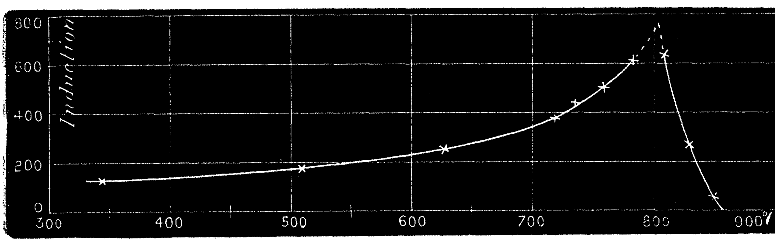


The only noteworthy features are that the coercive force is obviously somewhat considerable, and that the maximum induction is great—greater than that of the more nearly pure iron.

In Curve 2 are shown the results of induction in terms of the temperature for a force of 0·50.

CURVE 2.

1 per cent. Nickel. Magnetising Force, 0·50.



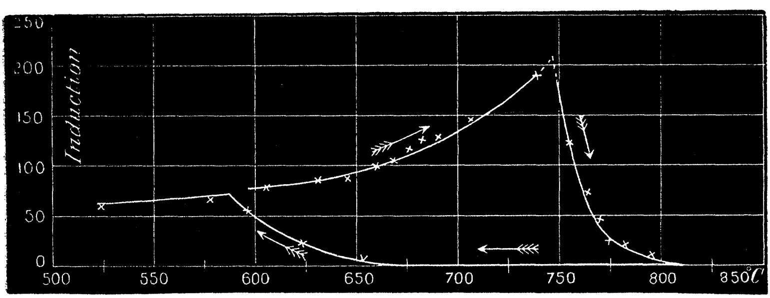
B. The following is the analysis of the sample:—

Fe.	Ni.	C.	Mn.	S.	P.	Si.	
94·799	4·7	0·22	0·23	0·014	0·037	trace	per cent.

We have here results of induction in terms of temperature for a magnetising force of 0·12, shown in Curve 3, and for comparison

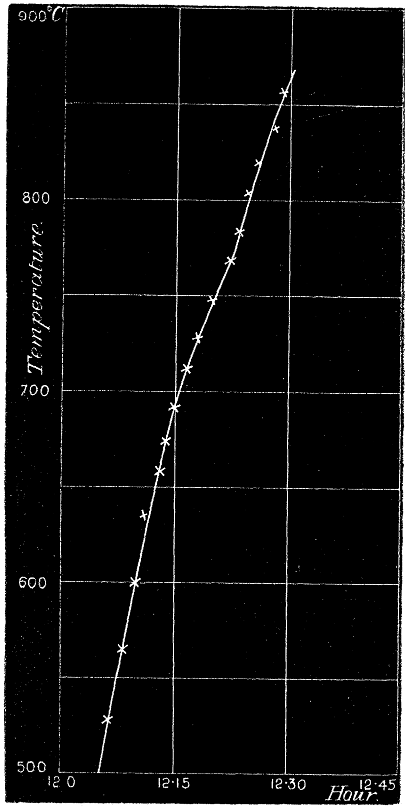
CURVE 3.

4·7 per cent. Nickel. Magnetising Force, 0·12.



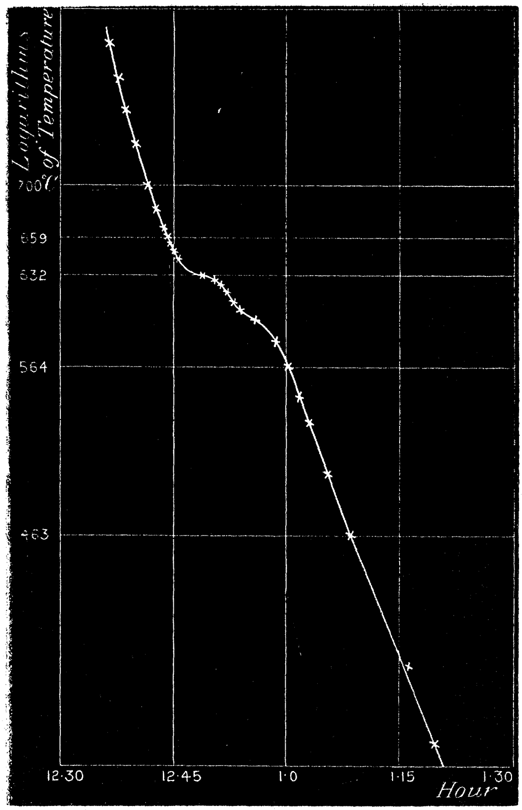
therewith the results of rate of heating and cooling in Curves 4 and 5 respectively. The experiment with rising temperature was made by simply observing with a watch the hour at which the temperature attained successive values whilst the piece was in the furnace; the cooling experiments were made in exactly the way described in 'Phil. Trans.,' A, 1889, p. 463; in the experiment with rising temperature, however (Curve 4), the ordinates are the actual temperatures, not

CURVE 4.



the logarithms of the excess of temperature above the room, as in Curve 5. The most remarkable feature in Curve 3 is that the material has two critical temperatures, one at which it ceases to be magnetisable with increase of temperature, the other, and lower, at which it again becomes magnetisable as the temperatures fall, and that these temperatures differ by about 150° C. Between these temperatures, then, the material can exist in either of two states—a magnetisable and a non-magnetisable. Note, further, that the curve for decreasing temperature returns into that for increasing temperature, and does not attain to the high value reached when the temperature is increasing. From Curve 4 we see that there is absorption of heat about 750° C., and not before; and from Curve 5 that heat is given off at 632° C., and again at a lower temperature. Comparing these temperatures with Curve 3, it is apparent that the

CURVE 5.



absorption and liberation of heat occur at the same temperature as the loss and return of the capacity for magnetism. From Curve 5 also we may infer that the latent heat liberated in cooling is about 150 times the heat liberated when the temperature of the material falls 1° C. Concerning the latent heat absorbed in heating, nothing can be inferred from Curve 4, excepting the temperature at which it is absorbed.

C. This alloy is very similar to the last; its analysis is—

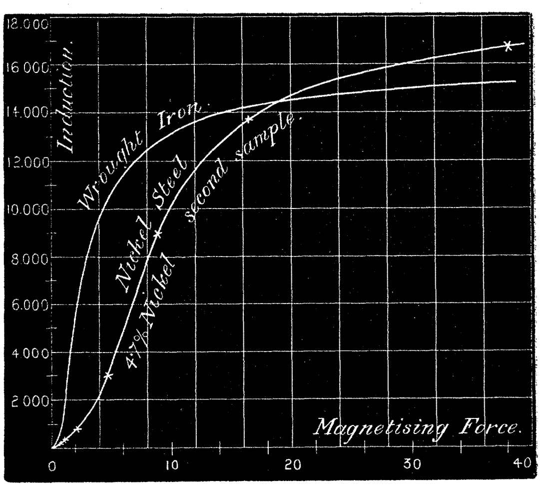
Fe.	Ni.	C.	Mn.	S.	P.	
94·39	4·7	0·27	0·57	0·03	0·04	per cent.

In Table II are given the results of observations of induction in terms of magnetising force at the ordinary temperature of the room; and in curve 6 these are plotted together with the curve for wrought iron.

Table II.

Magnetising force.		Induction.
0·06	......	14
0·12	......	29
0·25	......	60
0·52	......	127
1·05	......	294
2·10	......	760
4·6	......	3,068
8·7	......	8,786
16·6	......	13,641
38·5	......	16,702
266·5	......	21,697

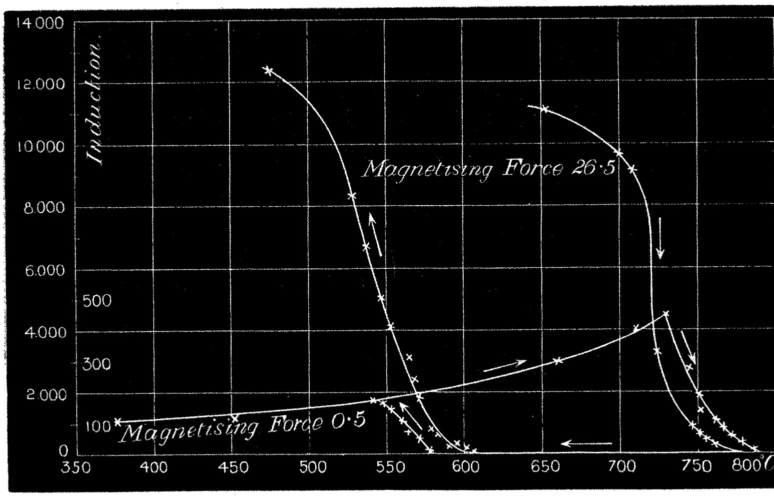
Curve 6.



The material appears to be capable of considerably higher magnetisation than wrought iron. In Curve 7 is shown the relation of induction and temperature for two forces, 26·5 and 0·5, the results being obtained on two different days, to the same scale of abscissæ but different scales of ordinates. These curves show the same features as the alloy B, but at a rather lower temperature.

D. This sample contains 22 per cent. of nickel. It was not thoroughly tested, as the supply of CO_2 which happened to be available was insufficient. Its magnetic properties, however, were similar to the next sample.

Curve 7.



E. The analysis of this sample* was—

Fe.	Ni.	C.	Mn.	S.	P.	Si.	
74·31	24·5	0·27	0·85	0·01	0·04	0·02	per cent.

As the material was given to me it was non-magnetisable at ordinary temperature; that is to say, the permeability was small, about 1·4, and the induction was precisely proportional to the magnetising force. The ring on being heated remained non-magnetisable up to 700° C. or 800° C. A block of the material did not recalesce on being heated to a high temperature and being allowed to cool.

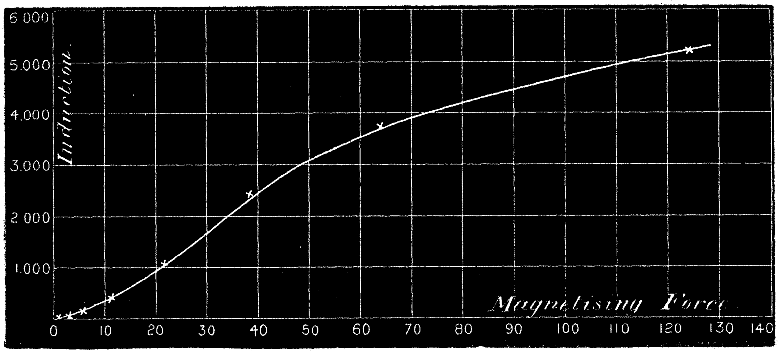
On being placed in a freezing mixture, the material became magnetic at a temperature a little below freezing point.

The material was next cooled to a temperature of about −51° C. by means of solid carbonic acid. After the temperature had returned to 13° C. the curve of magnetisation was ascertained as shown in Curve 8; from this it will be seen that the ring of the material which was previously non-magnetisable at 13° C. is now decidedly magnetisable at the same temperature. On heating the material, it remained magnetisable until it reached a temperature of 580° C. At this temperature it became non-magnetisable, and, on cooling, remained non-magnetisable at the ordinary temperature of the room. Curve 9 shows the induction at various temperatures for a magnetis-

* The results with this sample have already been presented to the Royal Society ('Proceedings,' vol. 47, pp. 23 and 188), but are repeated now for completeness.

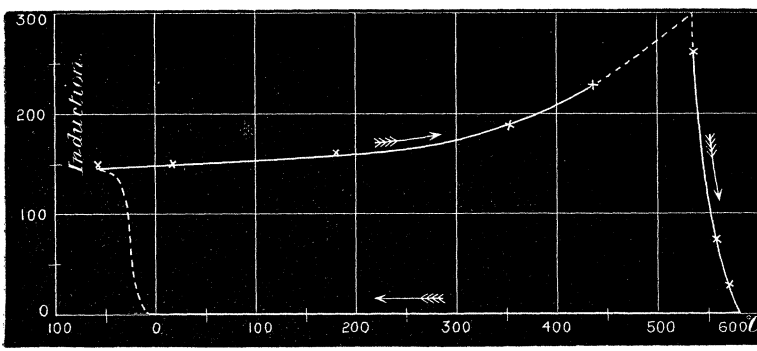
Curve 8.

25 per cent. Nickel.



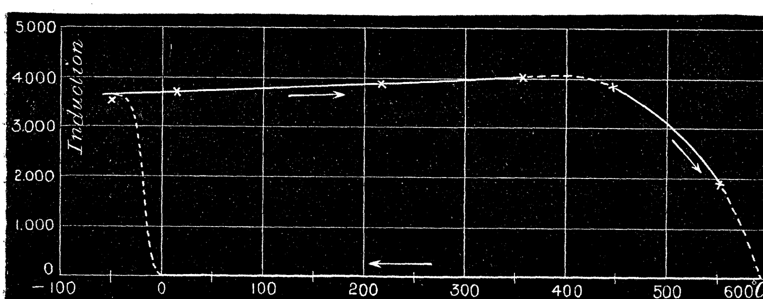
Curve 9.

Magnetising Force, 6·7. 25 per cent. Nickel.



Curve 10.

Magnetising Force, 64.



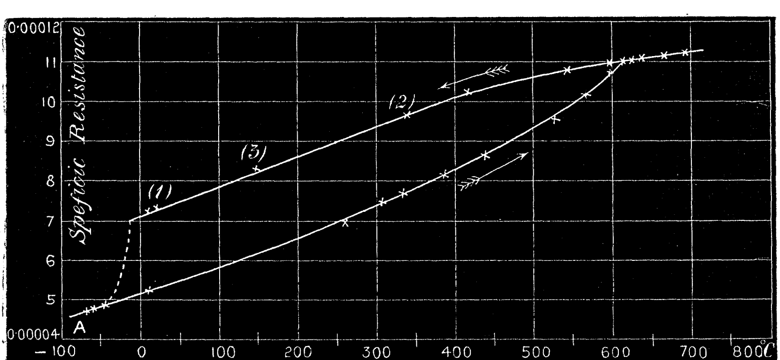
ing force 6·7; whilst Curve 10 shows the induction in terms of the temperature to a different scale for a force of 64. These curves show that, through a range of temperature from somewhat below freezing to 580° C., this material exists in two states, either being quite stable, the one being non-magnetisable, the other magnetisable. It changes from non-magnetisable to magnetisable if the temperature be reduced a little below freezing; the magnetisable state of the material does not change from magnetisable to non-magnetisable until the temperature is raised to 580° C.

The same kind of thing can be seen in a much less degree with ordinary steel. Over a small range this can exist in two states; but in changing its state from non-magnetisable to magnetisable a considerable amount of heat is liberated, which causes rise of temperature in the steel. It is observed in samples B and C of nickel steel, as we have just seen, but at a higher temperature.

As might be expected, the other physical properties of this material change with its magnetic properties. Mr. Riley has kindly supplied me with wire.

The wire as sent to me was magnetisable as tested by means of a magnet in the ordinary way. On heating it to a dull redness it became non-magnetisable, whether it was cooled slowly or exceedingly rapidly, by plunging it into cold water. A quantity of the wire was brought into the non-magnetisable state by heating it and allowing it to cool. The electric resistance of a portion of this wire, about 5 metres in length, was ascertained in terms of the temperature; it was first of all tried at the ordinary temperature, and then at temperatures up to 340° C. The specific resistances at these temperatures are indicated in Curve 11 by the numbers 1, 2, 3. The wire was then cooled by means of solid carbonic acid. The supposed course of change of resistance is indicated by the dotted line on the curve; the actual

CURVE 11.



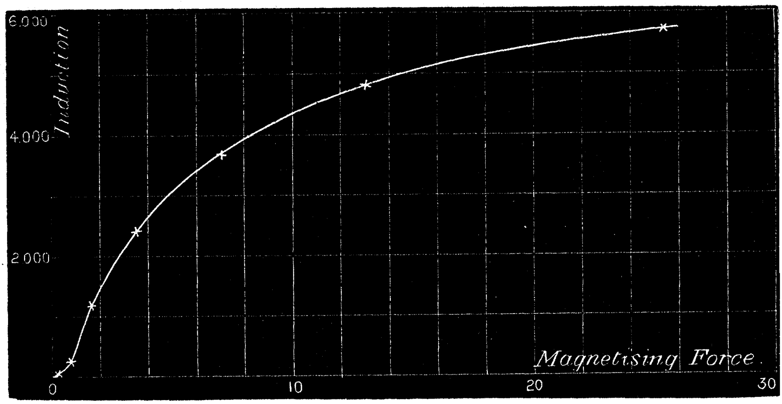
observations of resistance, however, are indicated by the crosses in the neighbourhood of the letter A on the curve. The wire was then allowed to return to the temperature of the room, and was subsequently heated, the actual observations being shown by crosses on the lower branches of the curve, the heating was continued to a temperature of 680° C., and the metal was then allowed to cool, the actual observations being still shown by crosses. From this curve it will be seen that in the two states of the metal (magnetisable and non-magnetisable) the resistances at ordinary temperatures are quite different. The specific resistance in the magnetisable condition is about 0·000052; in the non-magnetisable condition it is about 0·000072. The curve of resistance in terms of the temperature of the material in the magnetisable condition has a close resemblance to that of soft iron, excepting that the coefficient of variation is much smaller, as, indeed, one would expect in the case of an alloy; at 20° C. the coefficient is about 0·00132; just below 600° C. it is about 0·0040, and above 600° C. it has fallen to a value less than that which it had at 20° C. The change in electrical resistance effected by cooling is almost as remarkable as the change in the magnetic properties.

Samples of the wire were next tested in Professor Kennedy's laboratory for mechanical strength. Five samples of the wire were taken which had been heated and were in the non-magnetisable state, and five which had been cooled and were in the magnetisable state. There was a marked difference in the hardness of these two samples; the non-magnetisable was extremely soft, and the magnetisable tolerably hard. Of the five non-magnetisable samples the highest breaking stress was 50·52 tons per square inch, the lowest 48·75; the greatest extension was 33 per cent., the lowest 30 per cent. Of the magnetisable samples, the highest breaking stress was 88·12 tons per square inch, the lowest 85·76; the highest extension was 8·33, the lowest 6·70. The broken fragments, both of the wire which had originally been magnetisable and that which had been non-magnetisable, were now found to be magnetisable. If this material could be produced at a lower cost, these facts would have a very important bearing. As a mild steel, the non-magnetisable material is very fine, having so high a breaking stress for so great an elongation at rupture. Suppose it were used for any purpose for which a mild steel is suitable on account of this considerable elongation at rupture, if exposed to a sharp frost its properties would be completely changed —it would become essentially a hard steel, and it would remain a hard steel until it had actually been heated to a temperature of 600° C.

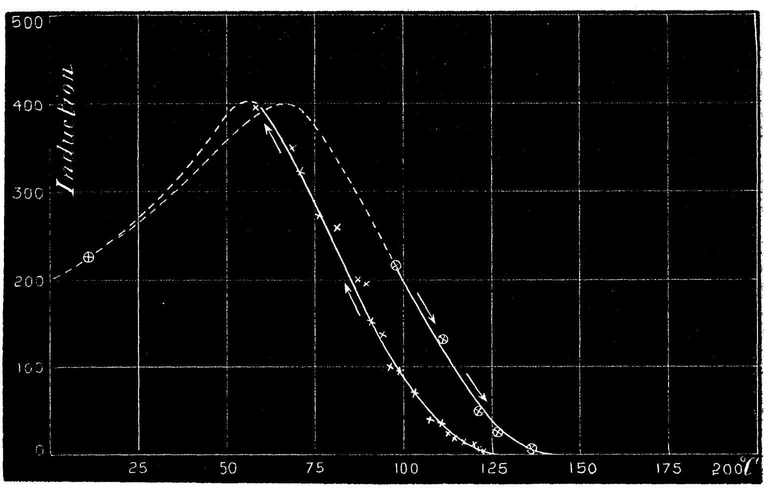
F. This sample contains 30 per cent. of nickel. Curve 12 shows the relation of induction to magnetising force at the ordinary temperature, and Curve 13 the relation of induction and temperature for

CURVE 12.

30 per cent. Nickel.



CURVE 13.



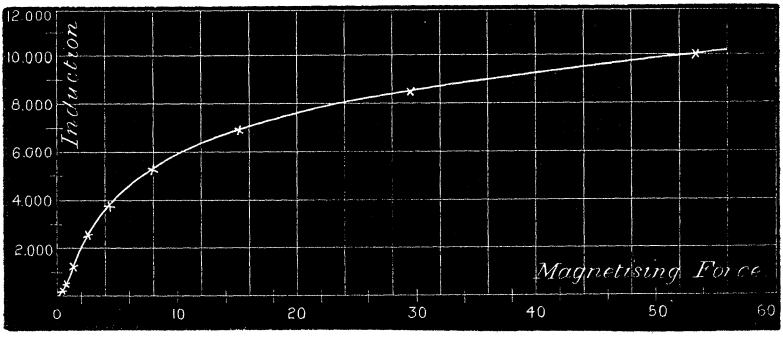
a force of 0·65. The remarkable feature here is the low temperature at which the change between magnetisable and non-magnetisable occurs, whether the temperature is rising or falling. Comparing it with the last sample, we see that the character of the material with regard to magnetism is entirely changed.

G. The analysis of this sample is—

Fe.	Ni.	C.	Mn.	S.	P.	
66·19	33·0	0·28	0·50	0·01	0·02	per cent.

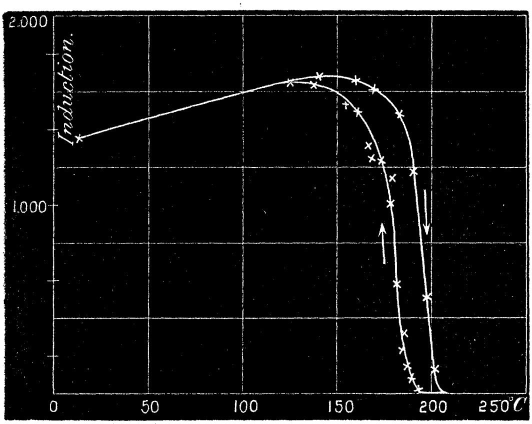
CURVE 14.

33 per cent. Nickel.



CURVE 15.

Magnetising Force, 1·0.



In Curve 14 is given the relation of induction and force at the ordinary temperature, and in Curves 15 and 16 the relation of induction and temperature for forces 1·0 and 30·3. The remarkable feature of this material is the complete difference from the last but one, and the low temperature of change. There is but very little difference between the temperatures of change when heated and when cooled.

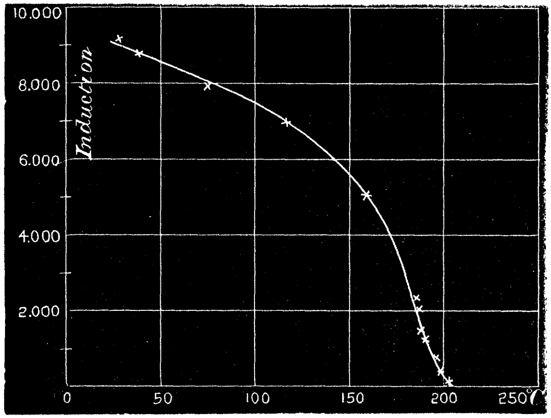
H. The analysis of this sample, as furnished by Mr. Riley, is—

Fe.	Ni.	C.	Mn.	S.	P.	
26·50	73·0	0·18	0·30	0·01	0·01	per cent.

In Curve 17 is given the relation of induction and force at the ordi-

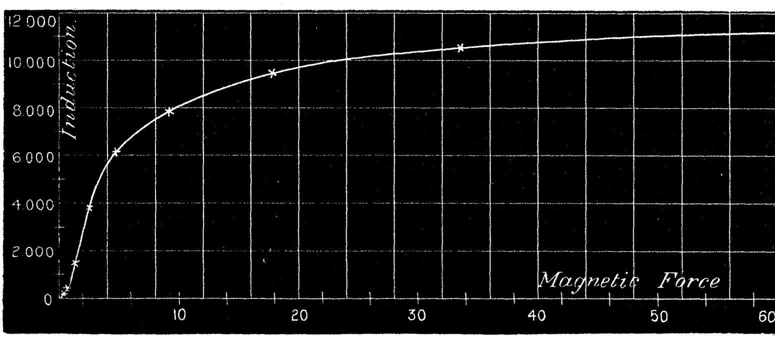
Curve 16.

Magnetising Force, 30·3.



Curve 17.

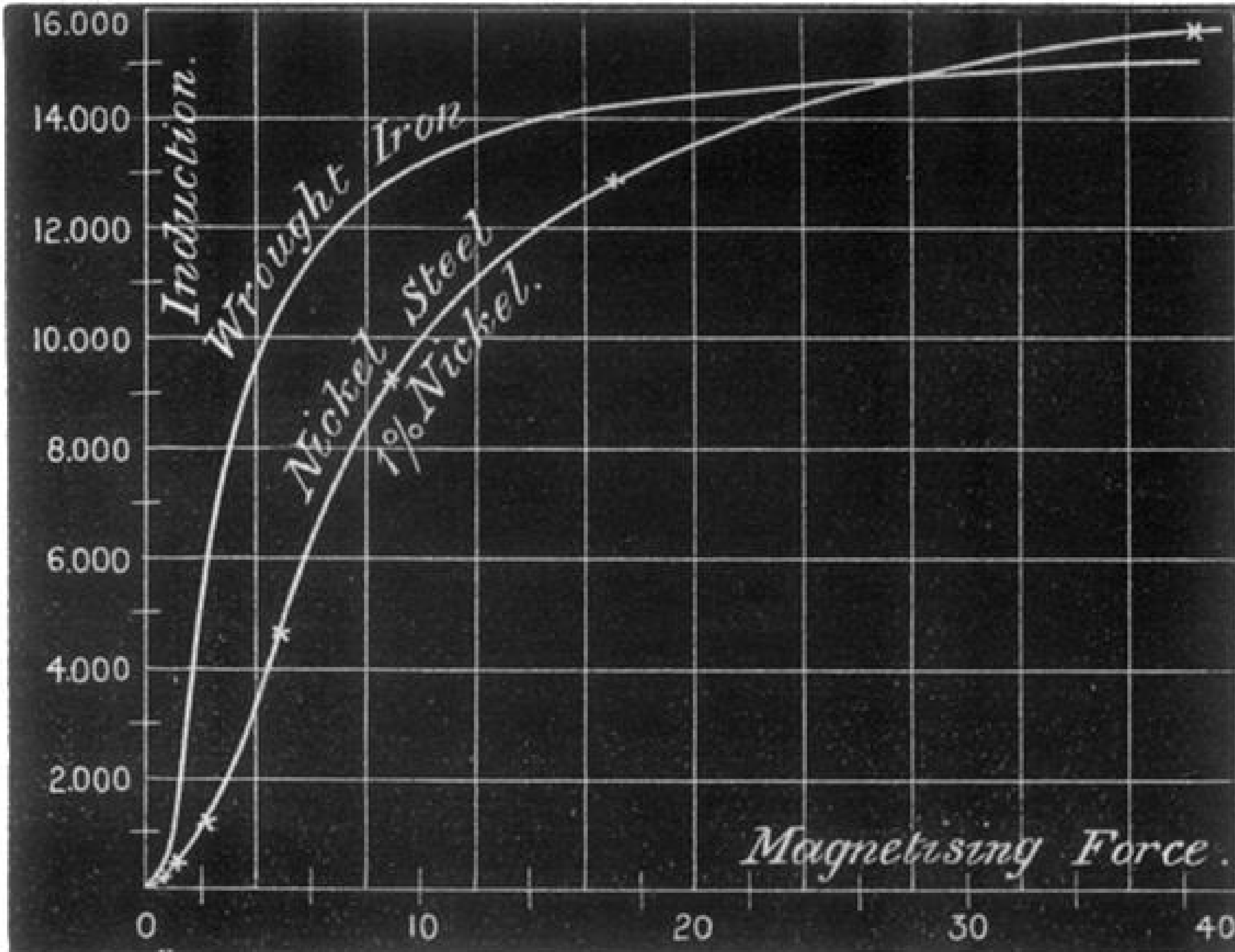
73 per cent. Nickel.



nary temperature. It is curious to remark that the induction for considerable forces is greater than in the steel with 33 per cent. of nickel, and that it is greater than for a mechanical mixture of iron and nickel in the proportions of the analysis, however the particles might be arranged in relation to each other.

The critical temperature of the material is 600° C.; it shows no material difference between the critical temperatures for increasing aud diminishing temperatures.

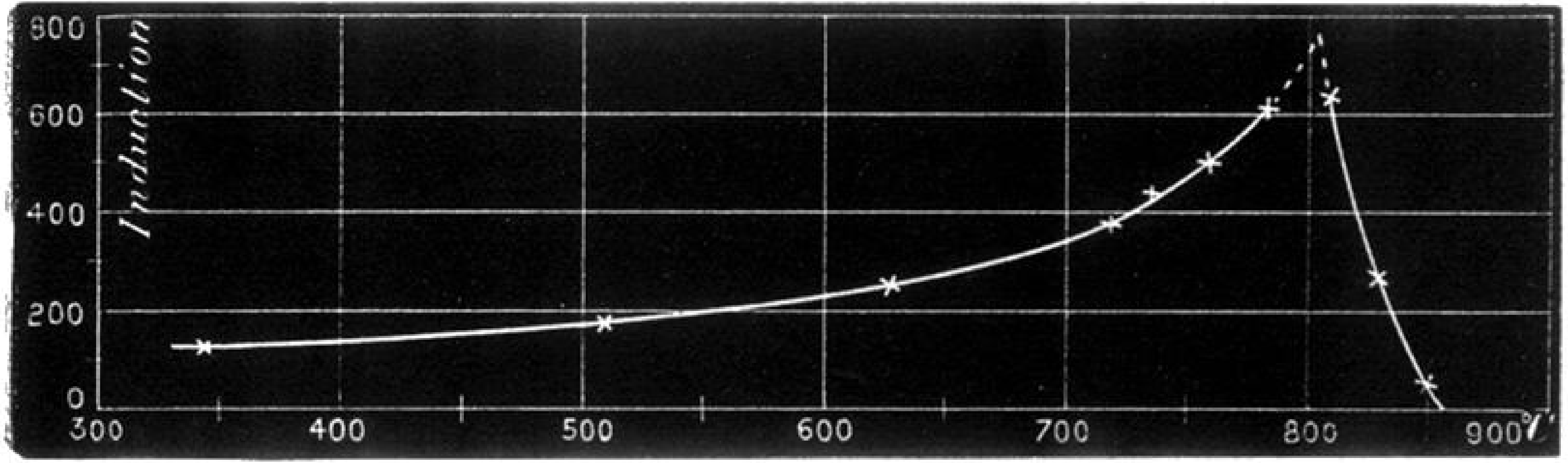
Curve 1.



16.000
14.000
12.000
10.000
8.000
6.000
4.000
2.000
Induction.
Wrought Iron
Nickel Steel
1% Nickel.
Magnetising Force.
0
10
20
30
40

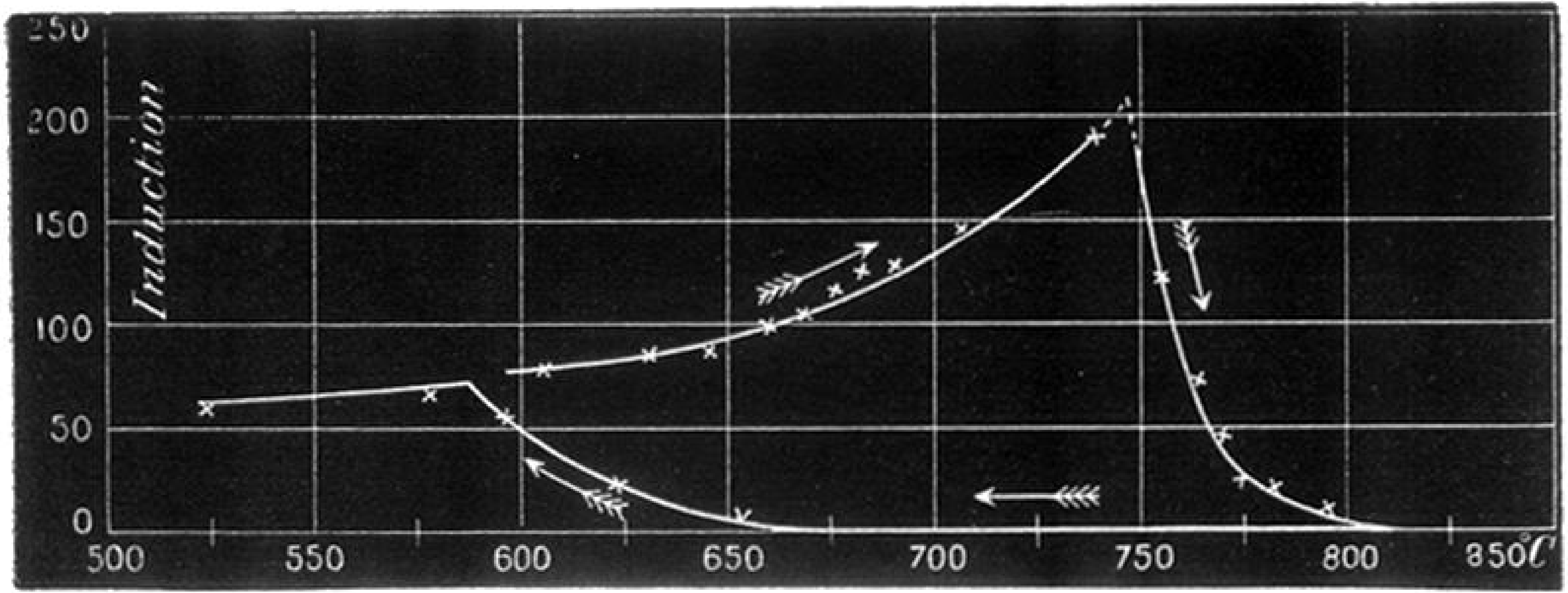
Curve 2.

1 per cent. Nickel. Magnetising Force, 0·50.

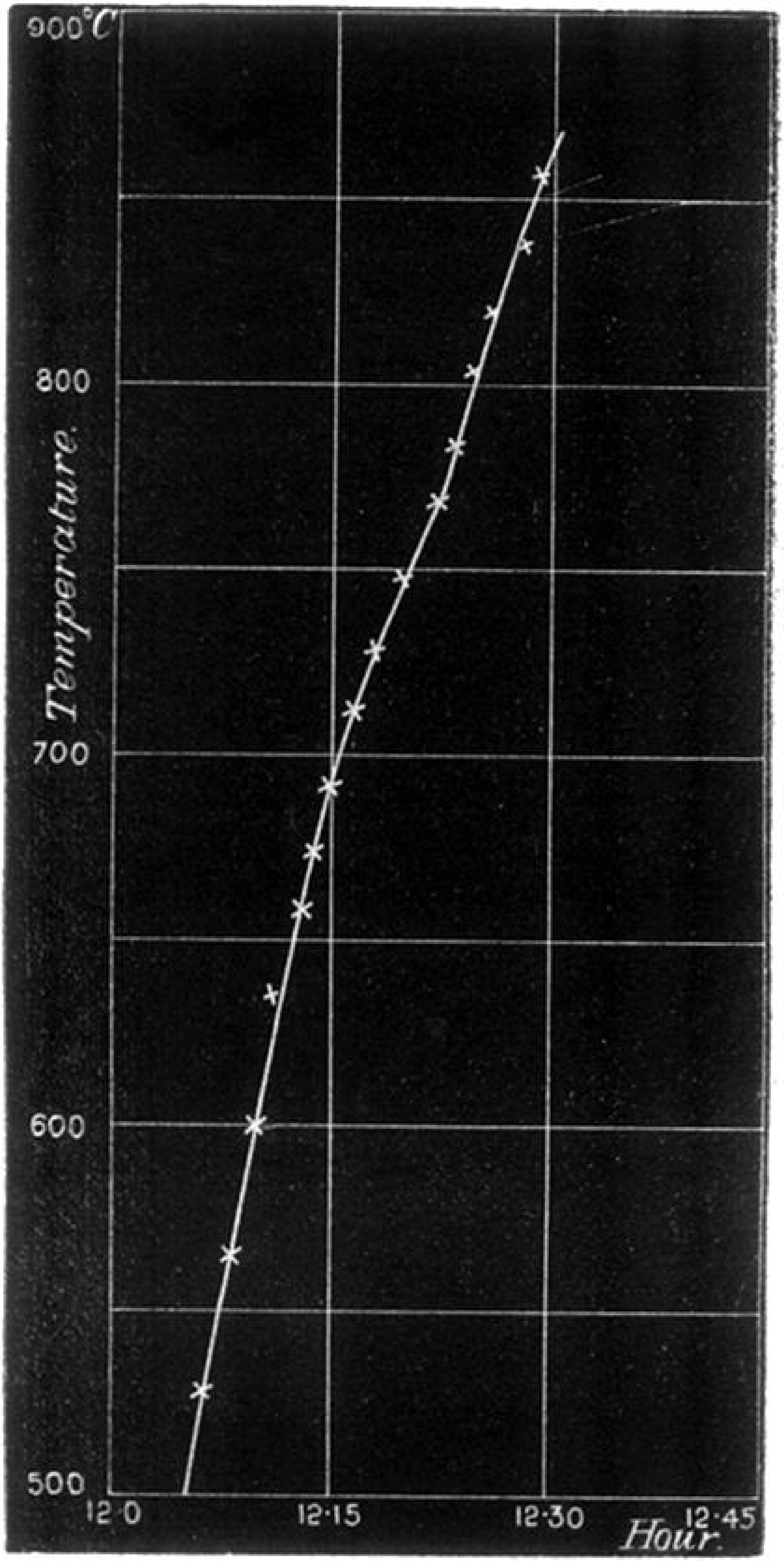


Curve 3.

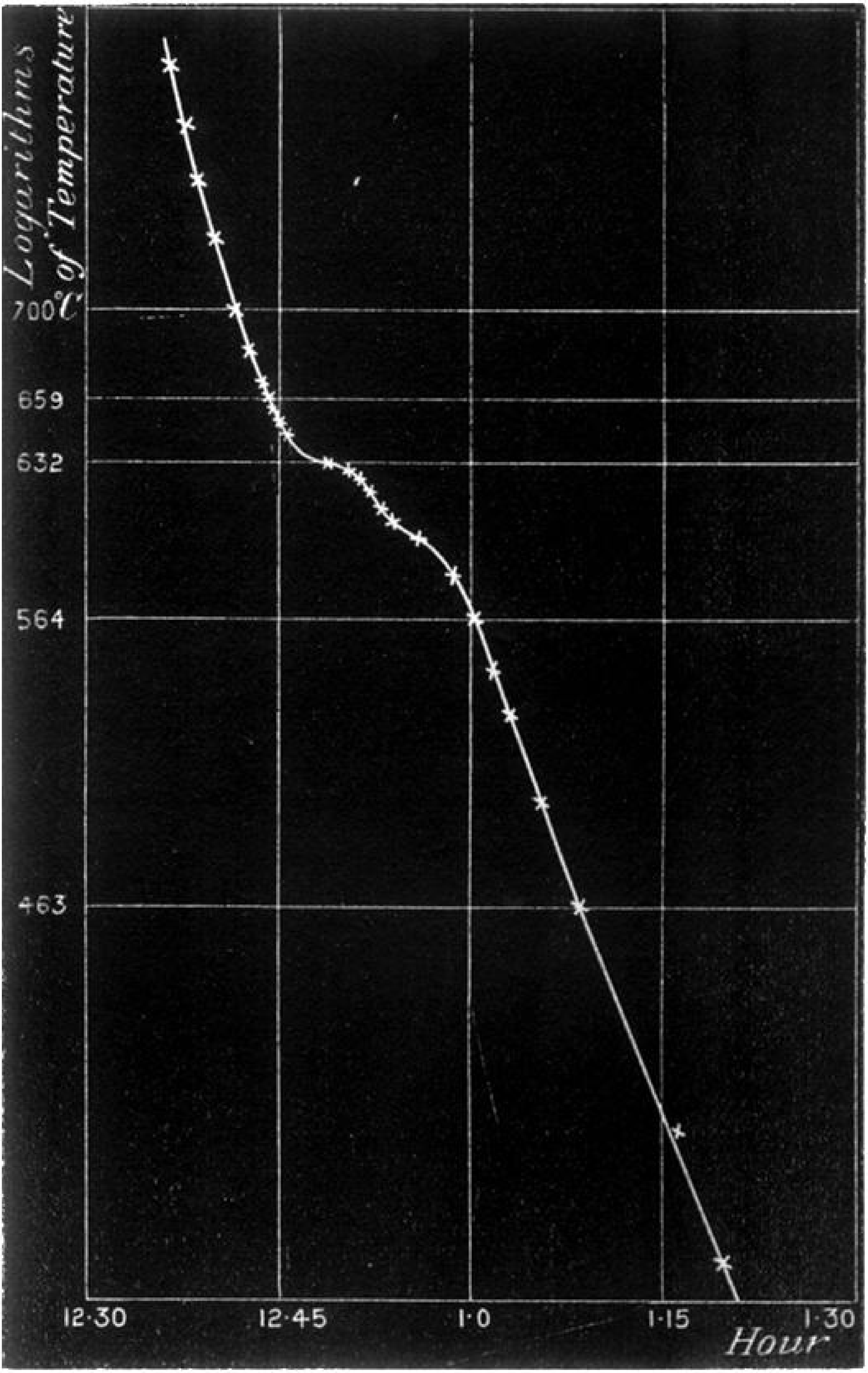
4·7 per cent. Nickel. Magnetising Force, 0·12.



CURVE 4.

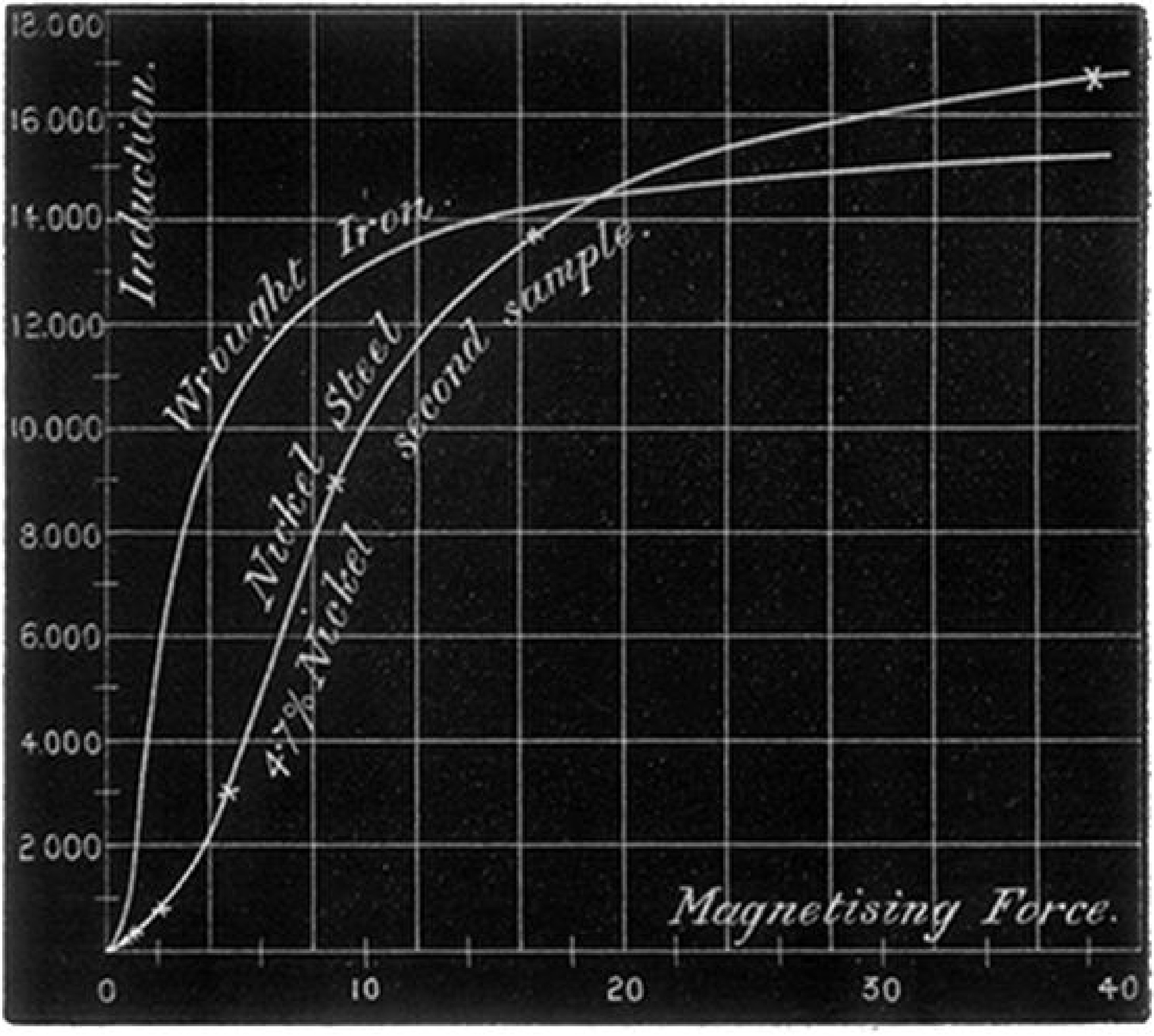


CURVE 5.



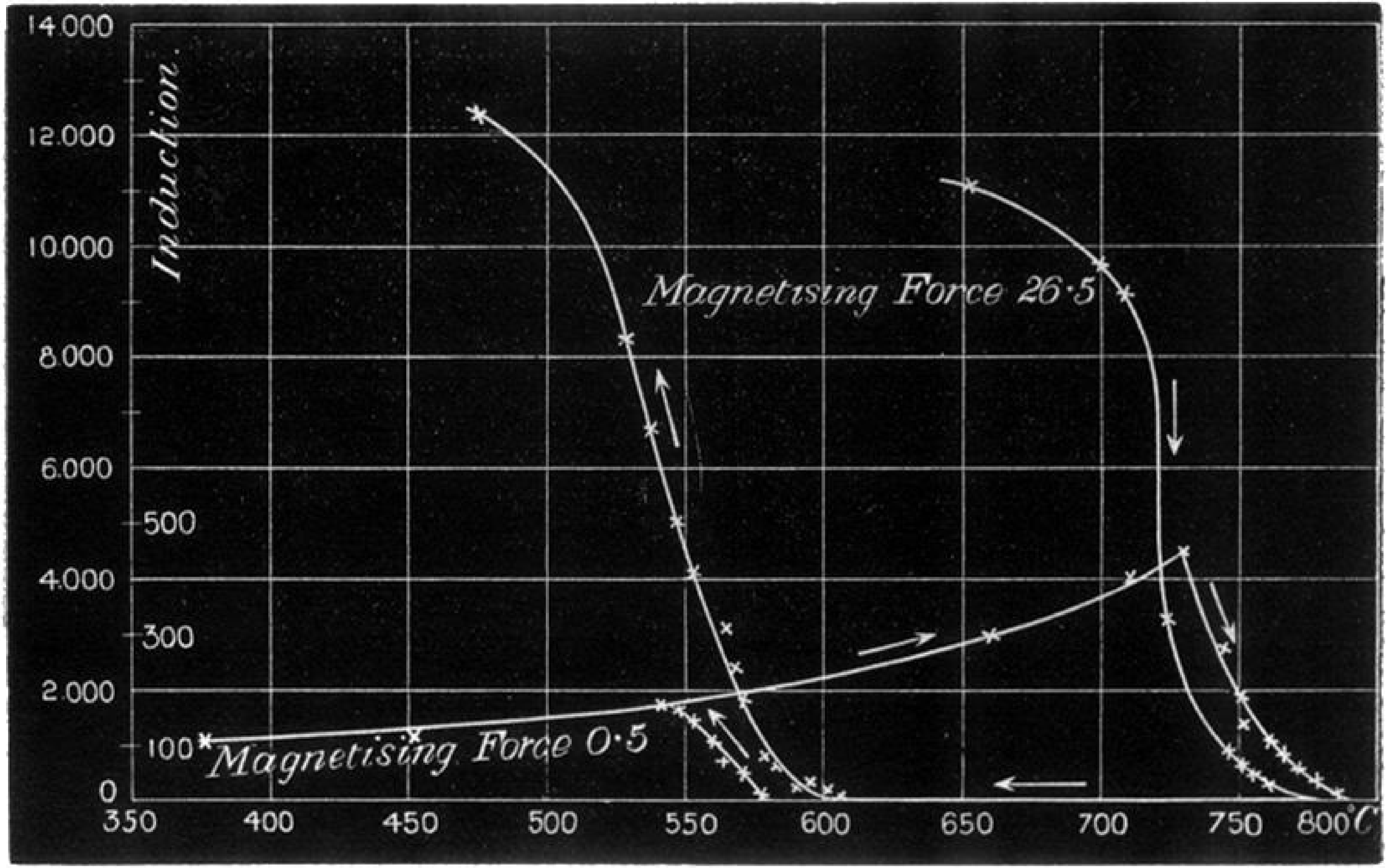
Logarithms of Temperature
700°C
659
632
564
463
12·30
12·45
1·0
1·15
1·30
Hour

CURVE 6.



Induction.
18.000
16.000
14.000
12.000
10.000
8.000
6.000
4.000
2.000
Wrought Iron.
Nickel Steel
second sample.
4·7% Nickel
Magnetising Force.
0
10
20
30
40

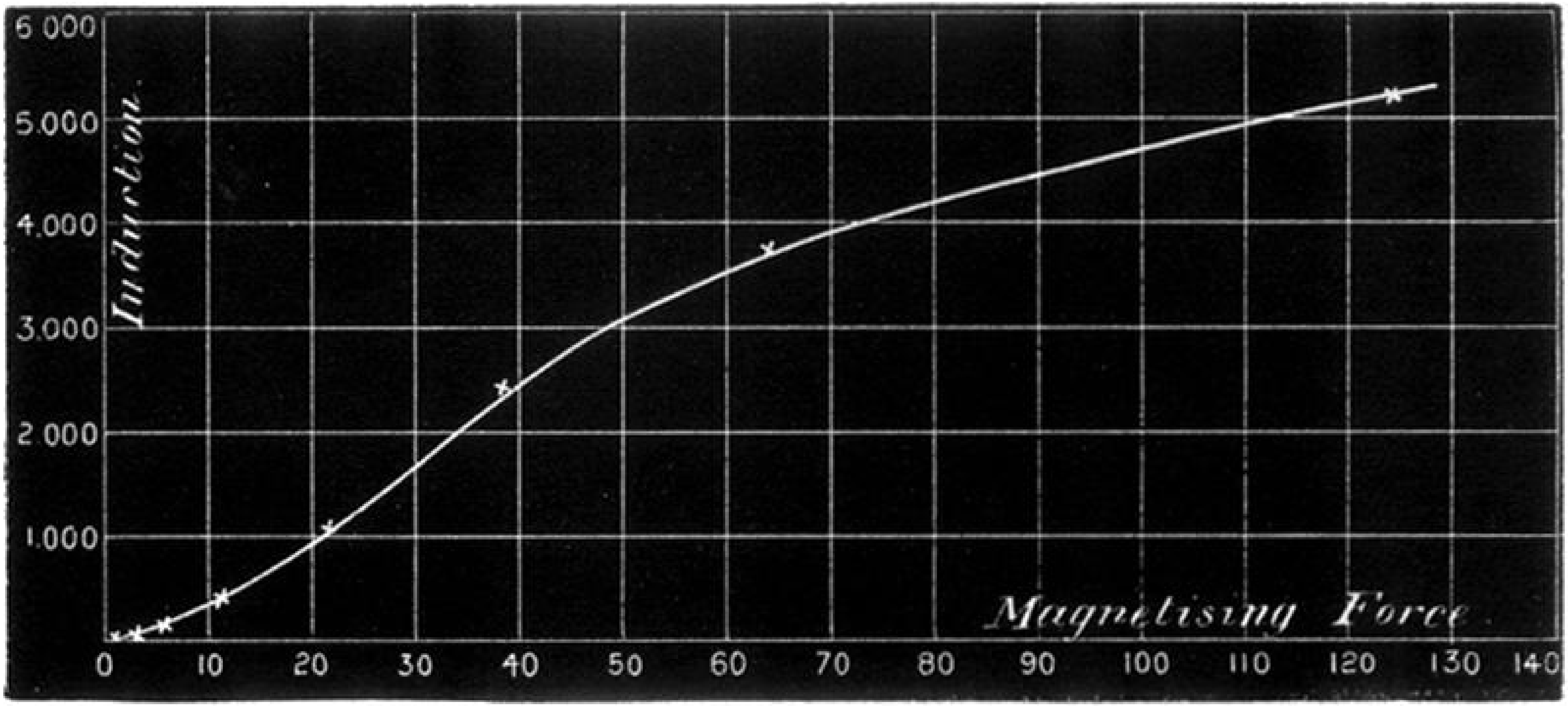
Curve 7.



Induction.
14.000
12.000
10.000
8.000
6.000
500
4.000
300
2.000
100
0
350
400
450
500
550
600
650
700
750
800°C
Magnetising Force 26·5
Magnetising Force 0·5

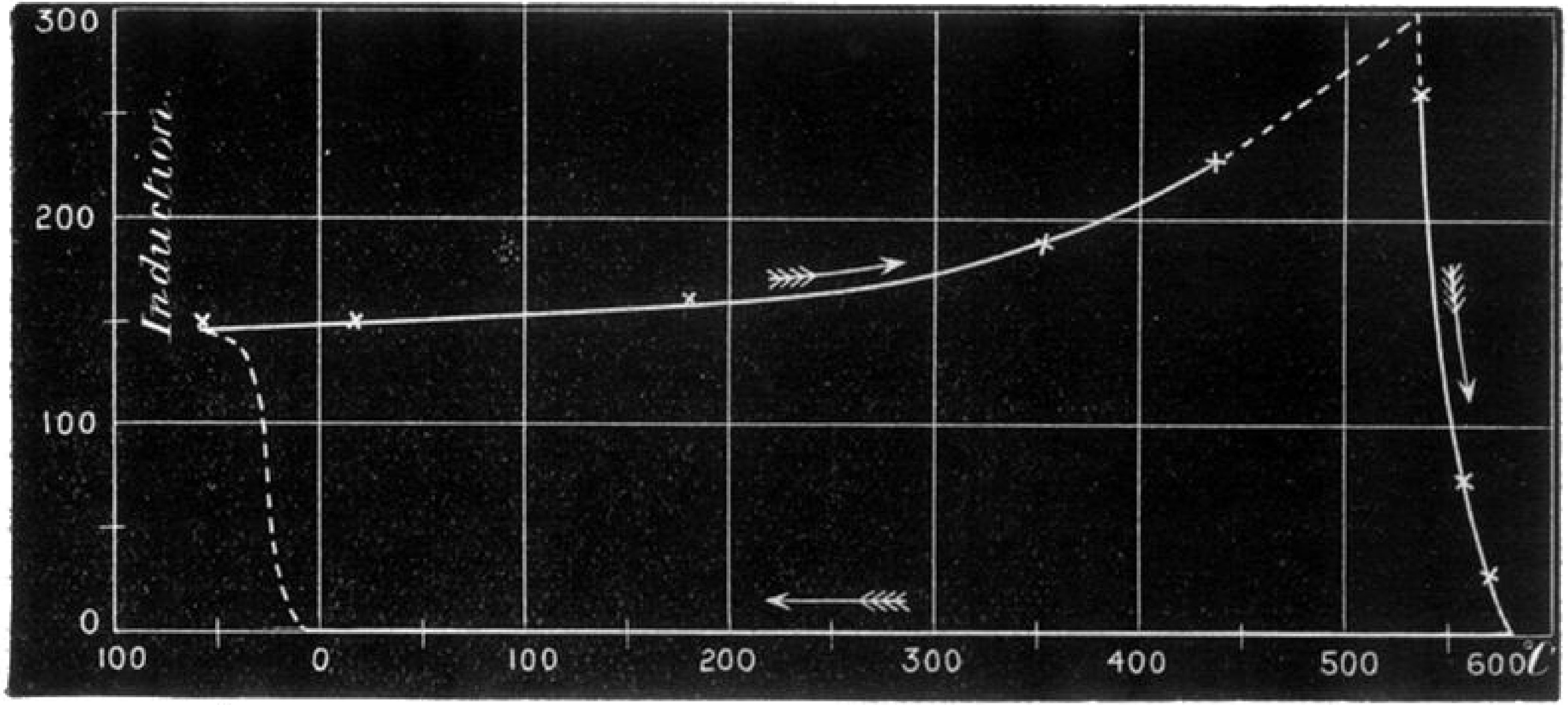
Curve 8.

25 per cent. Nickel.



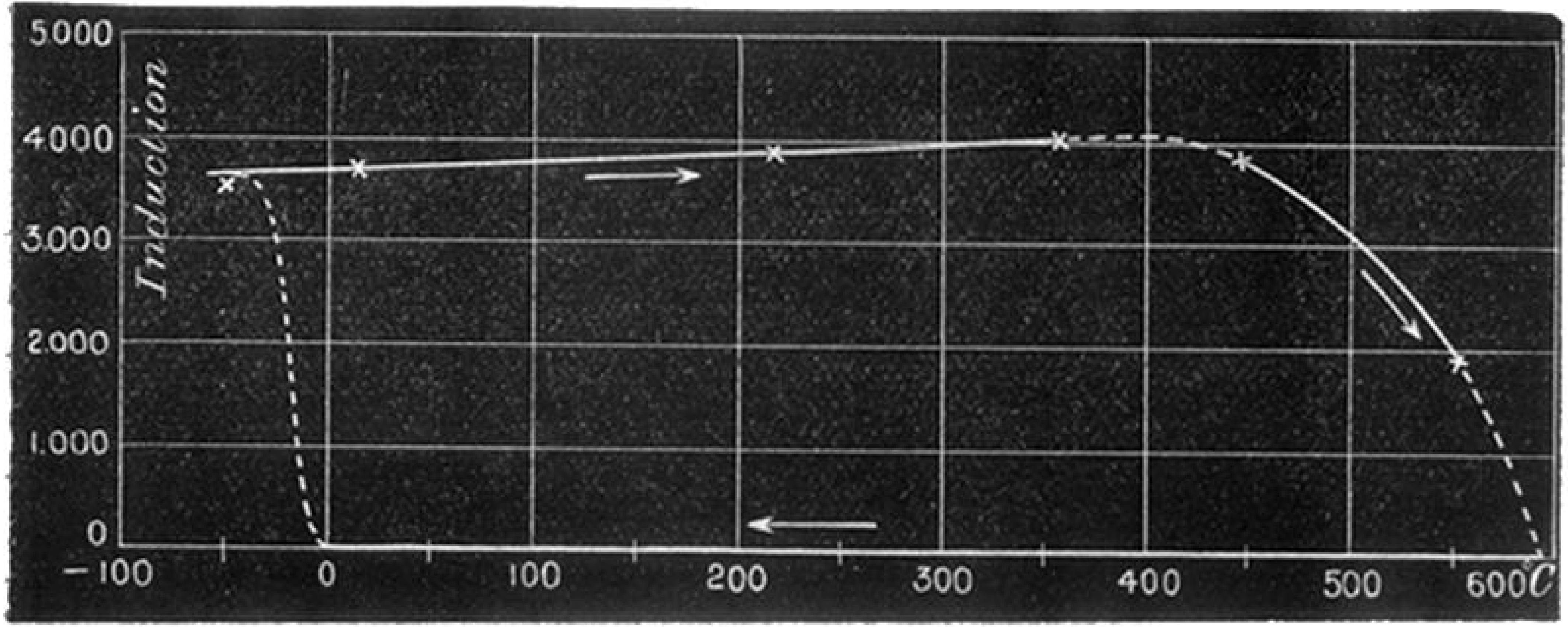
CURVE 9.

Magnetising Force, 6·7. 25 per cent. Nickel.

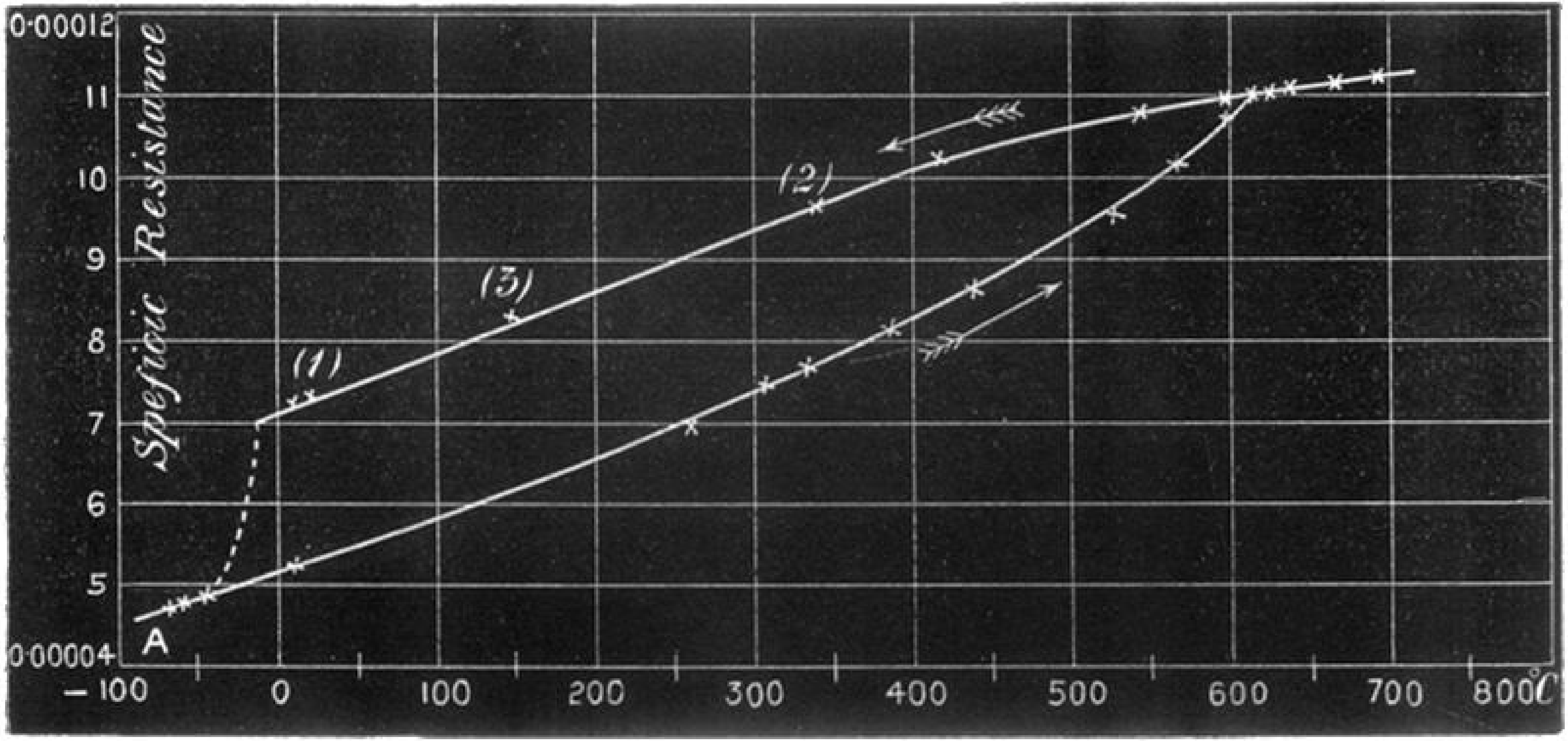


Curve 10.

Magnetising Force, 64.



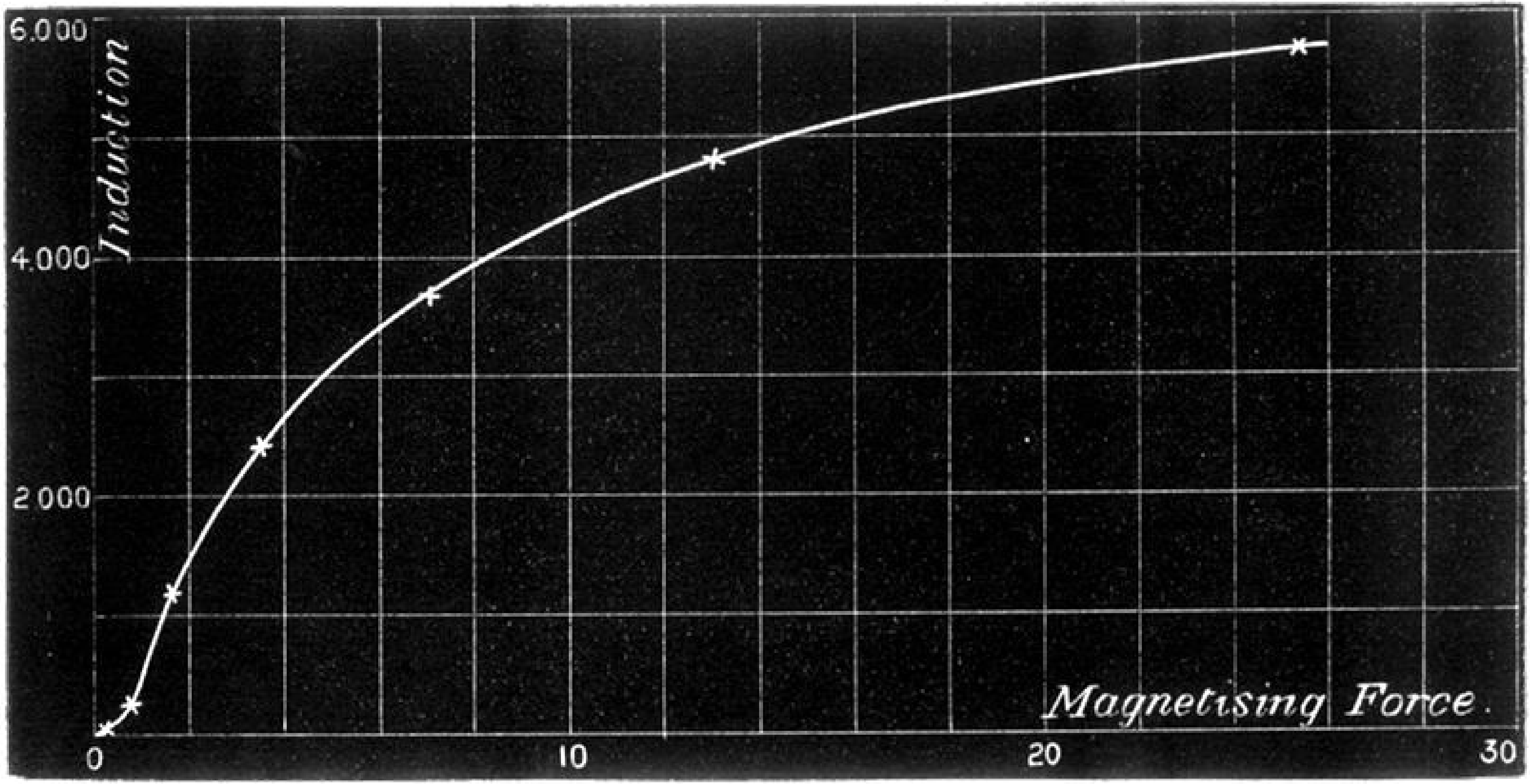
CURVE 11.



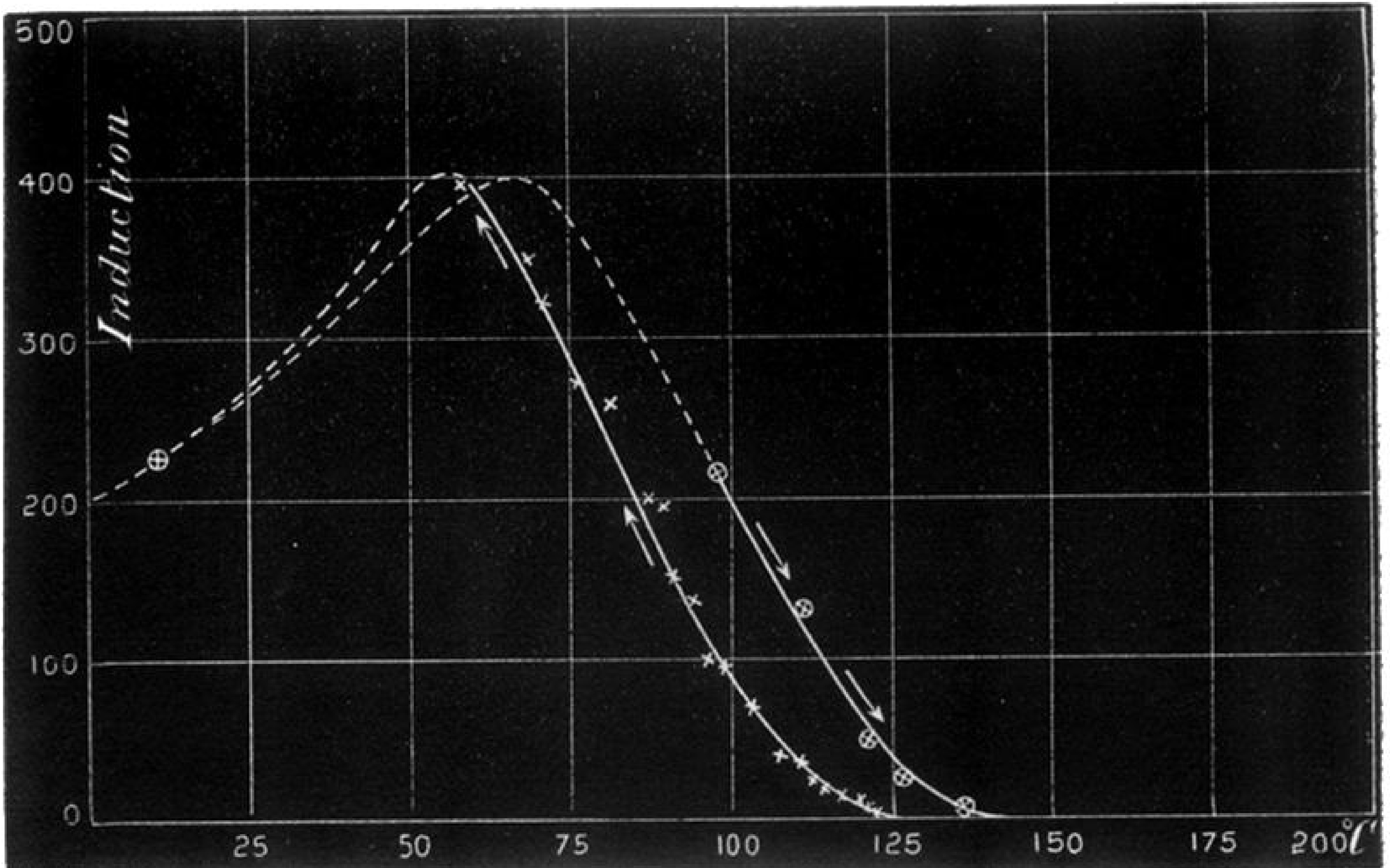
0·00012
11
10
9
8
7
6
5
0·00004
Specific Resistance
(1)
(2)
(3)
A
−100
0
100
200
300
400
500
600
700
800°C

CURVE 12.

30 per cent. Nickel.

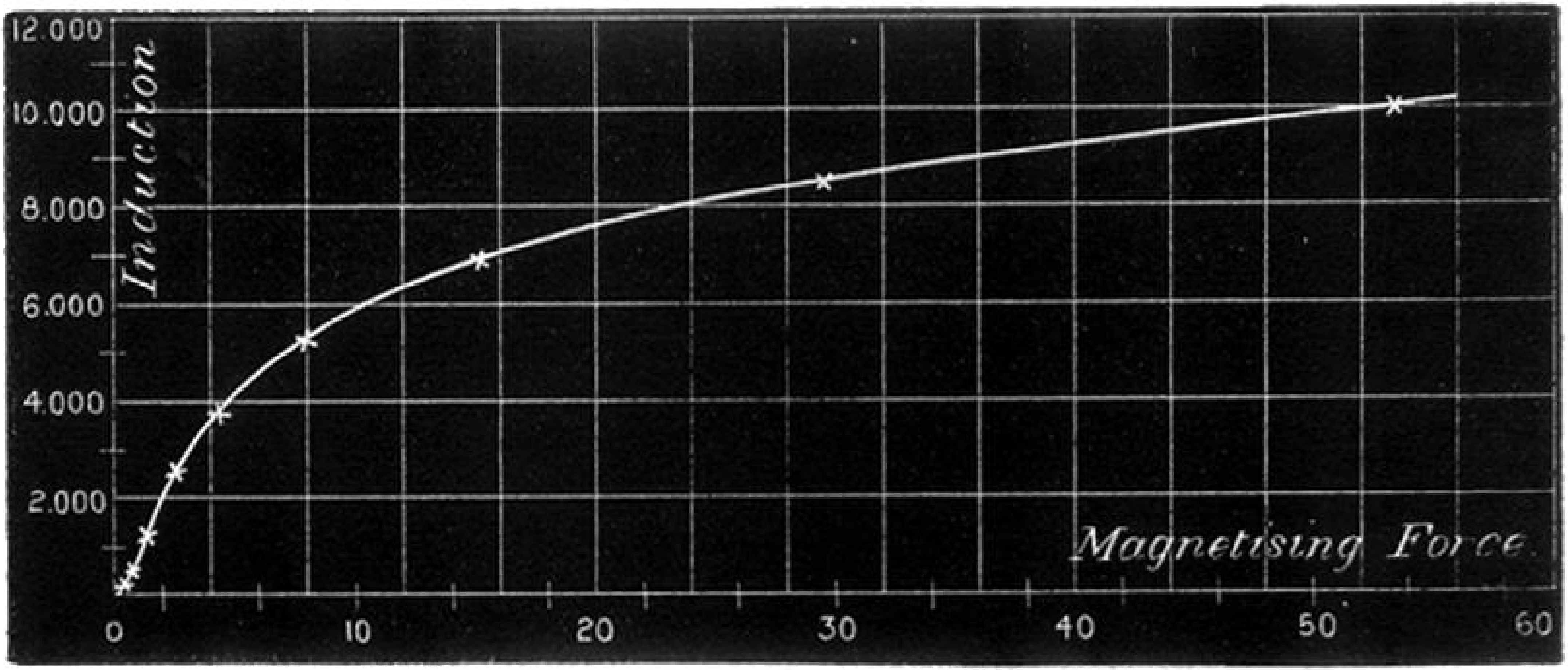


Curve 13.



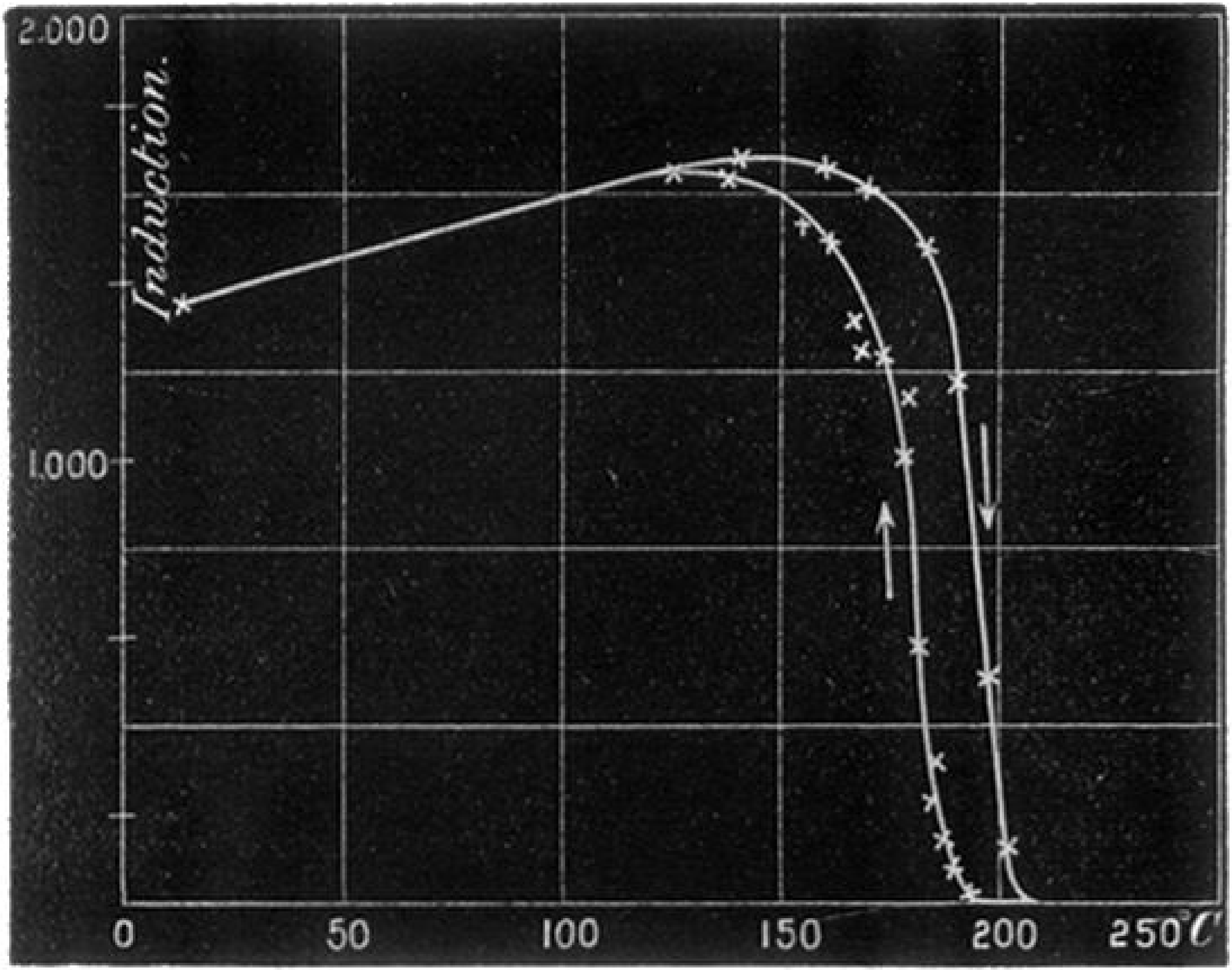
Curve 14.

33 per cent. Nickel.



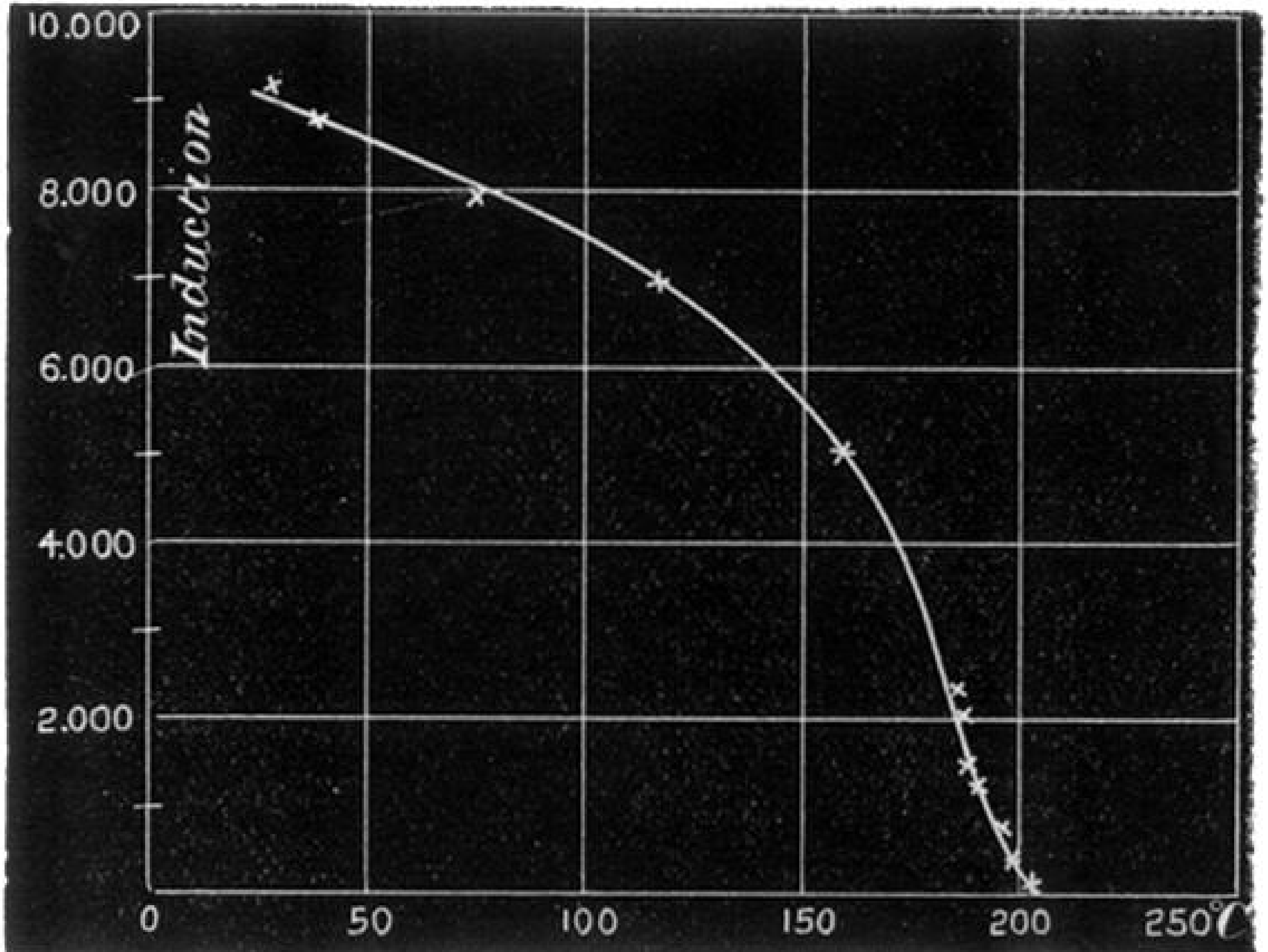
CURVE 15.

Magnetising Force, 1·0.



Curve 16.

Magnetising Force, 30·3.



Curve 17.

73 per cent. Nickel.